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From the QUARTERLY REVIEW, *Oct.* 1873.

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INTRODUCTION.

SPECIAL RESULTS OF OBSERVATION IN THE DOMAIN OF TELLURIC PHENOMENA.

In a work embracing so wide a field as the Cosmos, which aims at combining perspicuous comprehensibility with general clearness, the composition and co-ordination of the whole are perhaps of greater importance than copiousness of detail. This mode of treating the subject becomes the more desirable because, in the Book of Nature, the generalization of views, both in reference to the objectivity of external phenomena and the reflection of the aspects of nature upon the imagination and feelings of man, must be carefully separated from the enumeration of individual results. The first two volumes of the Cosmos were devoted to this kind of generalization, in which the contemplation of the Universe was considered as one great natural whole, while at the same time care was taken to show how, in the most widely remote zones, mankind had, in the course of ages, gradually striven to discover the mutual actions of natural forces. Although a great accumulation of phenomena may tend to demonstrate their causal connection, a General Picture of Nature can only produce fresh and vivid impressions when, bounded by narrow limits, its perspicuity is not sacrificed to an excessive aggregation of crowded facts.

As in a collection of graphical illustrations of the surface and of the inner structure of the earth's crust, general maps precede those of a special character, it has seemed to me that in a physical description of the Universe it would be most appropriate, and most in accordance with the plan of the present work, if, to the consideration of the entire Universe from general and higher points of view, I were to append in the latter volumes those special results of observation upon

those forms of speech, which refer to the ordained course of the celestial bodies. The known laws which rule the celestial sphere excite perhaps the greatest admiration by their simplicity, based as they solely are, upon the mass and distribution of accumulated ponderable matter and upon its forces of attraction. The impression of the sublime, when it arises from that which is immeasurable and physically great, passes almost unconsciously to ourselves beyond the mysterious boundary which connects the metaphysical with the physical, and leads us into another and higher sphere of ideas. The image of the immeasurable, the boundless, and the eternal, is associated with a power which excites within us a more earnest and solemn tone of feeling, and which, like the impression of all that is spiritually great and morally exalted, is not devoid of emotion.

The effect which the aspect of extraordinary celestial phenomena so generally and simultaneously exerts upon entire masses of people, bears witness to the influence of such an association of feelings. The impression produced in excitable minds by the mere aspect of the starry vault of heaven is increased by profounder knowledge, and by the use of those means which man has invented to augment his powers of vision, and at the same time enlarge the horizon of his observation. A certain impression of peace and calmness blends with the impression of the incomprehensible in the universe, and is awakened by the mental conception of normal regularity and order. It takes from the unfathomable depths of space and time those features of terror which an excited imagination is apt to ascribe to them. In all latitudes man, in the simple natural susceptibility of his mind, prizes "the calm stillness of a starlit summer night."

Although magnitude of space and mass appertains more especially to the sidereal portion of cosmical delineation, and the eye is the only organ of cosmical contemplation, our telluric sphere has, on the other hand, the preponderating advantage of presenting us with a greater and a scientifically distinguishable diversity in the numerous elementary bodies of which it is composed. All our senses bring us in contact with terrestrial nature, and while astronomy, which, as the knowledge of moving luminous celestial bodies is most acces-

own solar system, as we learn from an important conversation which he had at Kensington with Conduit (*Cosmos*, vol. i, p. 120). The uniform image of homogeneous gravitating matter conglomerated into celestial bodies has occupied the fancy of mankind in various ways, and mythology has even linked the charm of music to the voiceless regions within the realms of space (*Cosmos*, vol. iv, pp. 431—434).

Amid the boundless wealth of chemically varying substances, with their numberless manifestations of force—amid the plastic and creative energy of the whole of the organic world, and of many inorganic substances—amid the metamorphosis of matter which exhibits an ever-active appearance of creation and annihilation, the human mind, ever striving to grasp at order, often yearns for simple laws of motion in the investigation of the terrestrial sphere. Even Aristotle in his Physics states, that "the fundamental principles of all nature are change and motion; he who does not recognise this truth recognises not nature herself" (*Phys. Auscult.* iii, 1 p. 200 Bekker), and referring to the difference of matter ("a diversity in essence"), he designates motion in respect to its qualitative nature, as a metamorphosis, ἀλλοίωσις, very different from mere mixture, μίξις, and a penetration which does not exclude the idea of subsequent separation (*De Gener. et Corrupt.* i, 1 p. 327).

The unequal ascent of fluids in capillary tubes—the endosmosis which is so active in all organic cells, and is probably a consequence of capillarity—the condensation of different kinds of gases in porous bodies (of oxygen in spongy platinum, with a pressure which is equal to a force of more than 700 atmospheres, and of carbonic acid in boxwood charcoal, when more than one-third is condensed in a liquid state on the walls of the cells)—the chemical action of contact-substances which, by their presence occasion or destroy (by *catalysis*) combinations without themselves taking any part in them—all these phenomena teach us that bodies at infinitely small distances exert an attraction upon one another, which depends upon their specific natures. We cannot conceive such attractions to exist independently of motions, which must be excited by them although inappreciable to our eyes.

We are still entirely ignorant of the relations which reci-

the solid and fluid matter on the outer crust of the earth." Although while it is not improbable, judging from geological data, that the incidental alterations which are readily brought about in the fused portions of the interior of the earth, when they are moved by a change of position of the masses, may even modify the *geometrical* surface by producing curvature of the meridians and parallels in small spaces, and at very widely separated periods of time; the *physical* surface of the oceanic parts of our globe is periodically subjected to a change of place in the masses, occasioned by the ebbing and flowing (or in other words the local depression and elevation) of the fluid element. The inconsiderable amount of the effects of gravity in continental regions may indeed render a gradual change inappreciable to actual observation; and according to Bessel's calculation, in order to increase the latitude of a place by a change of only 1″, it must be assumed that there is a transposition in the interior of the earth of a mass, whose weight (its density being assumed to be that of the mean density of the earth) is that of 7296 geographical cubic miles.[5] However large the volume of this transposed mass may appear to us when we compare it with the volume of Mont Blanc, or Chimborazo, or Kintschindjinga, our surprise at the magnitude of the phenomenon soon diminishes when we remember that our terrestrial spheroid comprises upwards of 1696 hundreds of millions of such cubic miles.

Three different methods have been attempted although with unequal success for solving the problem of the *figure of the earth* whose connection with the geological question of the earlier liquid condition of the rotating planetary bodies was known at the brilliant epoch of Newton, Huygens and Hooke.[6] These methods were the geodetico-astro-

[5] Bessel, *Ueber den Einfluss der Veränderungen des Erdkörpers auf die Polhöhen*, in Lindenau und Bohnenberger, *Zeitschrift für Astronomie.* Bd. v, 1818, s. 29. "The weight of the earth, expressed in German pounds$=9933 \times 10.^{21}$, and that of the transposed mass $= 947 \times 10.^{14}$."

[6] The theoretical labours of that time were followed by those of Maclaurin, Clairaut, and d'Alembert, by Legendre and by Laplace. To this latter period we may add the theorem advanced by Jacobi, in 1834, that ellipsoids of three unequal axes may, under certain conditions, represent the figures of equilibrium no less than the two previously-indicated ellipsoids of rotation.—See the treatise of this writer, whose

nomical measurement of a degree, pendulum experiments, and calculations of the inequalities in the latitude and longitude of the moon. In the application of the first method two separate processes are required, namely, measurements of a degree of latitude on the arc of a meridian, and measurements of a degree of longitude on different parallels.

Although seven years have now passed since I brought forward the results of Bessel's important labours, in reference to the dimensions of our globe, in my General Delineation of Nature, his work has not yet been supplanted by any one of a more comprehensive character, or based upon more recent measurements of a degree. An important addition and great improvements in this department of inquiry may, however, be expected on the completion of the Russian geodetic measurements, which are now nearly finished, and which, as they extend almost from the North Cape to the Black Sea, will afford a good basis of comparison for testing the accuracy of the results of the Indian survey.

According to the determinations published by Bessel in the year 1841, the mean value of the dimensions of our planet was, according to a careful investigation[7] of ten mea

early death has proved a severe loss to science, in Poggendorff's *Annalen der Physik und Chemie.* Bd. xxxiii, 1834, s. 229—233.

[7] The first accurate comparison of a large number of geodetic measurements (including those made in the elevated plateau of Quito, two East Indian measurements, together with the French, English, and recent Lapland observations) was successfully effected by Walbeck, at Abo, in 1819. He found the mean value for the earth's ellipticity to be $\frac{1}{302.781}$, and that of a meridian degree 57009.758 toises, or 324,628 feet. Unfortunately his work, entitled *De Forma et Magnitudine Telluris* has not been published in a complete form. Excited by the encouragement of Gauss, Eduard Schmidt was led to repeat and correct his results in his admirable Handbook of Mathematical Geography, in which he took into account both the higher powers given for the ellipticity, and the latitudes observed at the intermediate points, as well as the Hanoverian measurements and those which had been extended as far as Formentera by Biot and Arago. The results of this comparison have appeared in three forms, after undergoing a gradual correction, namely, in Gauss's *Bestimmung der Breitenunterschiede von Göttingen und Altona* 1828, s. 82; in Eduard Schmidt's *Lehrbuch der Mathem. und Phys. Geographie,* 1829, Th. 1, s. 183, 194—199; and lastly in the preface to the latter work (s. 5). The last result is, for a meridian degree 57008.655 toises, or 324,261 feet; for the ellipticity, $\frac{1}{297.479}$. Bessel's first work of 1830 had been immediately preceded by Airy's treatise on the *Figure of the Earth,*

surements of degrees, as follows :—The semi-axis major of a rotating spheroid, a form that approximates most closely to

in the Encyclopædia Metropolitana. Ed. of 1849, pp. 220—239. (Here the semi-polar axis was given at 20,853,810 feet=3949.585 miles, the semi-equatorial axis at 20,923,713 feet=3962.824 miles, the meridian quadrant at 32,811,980 feet, and the ellipticity at $\frac{1}{298.33}$). The great astronomer of Königsberg was uninterruptedly engaged, from 1836 to 1842, in calculations regarding the figure of the earth, and as his earlier works were emended by subsequent corrections, the admixture of results of investigations at different periods of time has, in many works, proved a source of great confusion. In numbers, which from their very nature are dependent on one another, this admixture is rendered still more confusing from the erroneous reduction of measurements; as, for instance, toises, metres, English feet, and miles of 60 and 69 to the equatorial degree; and this is the more to be regretted since many works, which have cost a very large amount of time and labour, are thus rendered of much less value than they otherwise would be. In the summer of 1837, Bessel published two treatises, one of which was devoted to the consideration of the influence of the irregularity of the earth's figure upon geodetic measurements, and their comparison with astronomical determinations, whilst the other gave the axes of the oblate spheroid, which seemed to correspond most closely to existing measurements of meridian arcs (Schum. *Astr. Nachr.* bd. xiv, No. 329, s. 269, No. 333, s. 345). The results of his calculation were 3271953.854 toises for the semi-axis major; 3261072.900 toises for the semi-axis minor; and for the length of a mean meridian degree, that is to say, for the ninetieth part of the earth's quadrant (vertically to the equator), 57011.453 toises. An error of 68 toises, or 440.8 feet, which was detected by Puissant, in the mode of calculation that had been adopted, in 1808, by a Commission of the National Institute for determining the distance of the parallels of Montjouy, near Barcelona, and Mola in Formentera, led Bessel, in the year 1841, to submit his previous calculations regarding the dimensions of the earth to a new revision. (Schum. *Astr. Nachr.* Bd. xix, No. 438, s. 97—116). This correction yielded for the length of the earth's quadrant 5131179.81 toises, instead of 5130740 toises, which had been obtained in accordance with the first determination of the metre; and for the mean length of a meridian degree, 57013.109 toises, which is about 0.611 of a toise more than a meridian degree, at 45° lat. The numbers given in the text are the result of Bessel's latest calculations. The length of the meridian quadrant, 5131180 toises, with a mean error of 255.63 toises, is therefore=10000856 metres, which would therefore give 40003423 metres, or 21563.92 geographical miles, for the entire circumference of the earth. The difference between the original assumption of the *Commission des Poids et Mesures*, according to which the metre was the forty-millionth part of the earth's circumference, amounts for the entire circumference to 3423 metres, or 1756.27 toises, which is almost two geographical miles, or more accurately

by one of the members, at a meeting of the Academy, according to which the weight of a body must be less at the equator than at the pole, in consequence of the rotation of the earth." He adds doubtfully, that although it would appear from certain experiments made in London, Lyons, and Bologna, as if the seconds-pendulum must be shortened the nearer we approach to the equator; yet on the other hand he was not sufficiently convinced of the accuracy of the measurements adduced, because at the Hague, notwithstanding its more northern latitude, the pendulum lengths were found to be precisely the same as at Paris. The periods at which Newton first became acquainted with the important pendulum results that had been obtained by Richer as early as 1672, although they were not printed until 1679, and at which he first heard of the discovery that had been made by Cassini, before the year 1666, of the compression of Jupiter's disc, have unfortunately not been recorded with the same exactness, as the fact of his very tardy acquaintance with Picard's measurement of a degree. In an age so remarkable for the successful emulation that distinguished the cultivators of science, and when theoretical views led to the prosecution of observations, which by their results reacted in their turn upon theory, it is of great interest to the history of the mathematical establishment of physical astronomy, that individual epochs should be determined with accuracy.

Although direct measurements of meridian and parallel degrees (the former especially in the case of the French measurement of a degree[15] between the latitudes 44° 42′ and 47° 30′, and the latter by the comparison of points lying to the east and west of the Italian and Maritime Alps),[16] exhibit great deviations from the mean ellipsoidal figure of the earth, the variations in the amount of ellipticity given by pendulum lengths (taken at different geographical points and in different groups) are very much more striking. The determination of the figure of the earth obtained from the

[15] Delambre, *Base du Syst. Métrique*, t. iii, p. 548.

[16] *Cosmos*, vol. i, p. 159. Plana, *Opérations Géodésiques et Astronomiques pour la Mesure d'un Arc du Parallèle Moyen*, t. ii, p. 847; Carlini in the *Effemeridi Astronomiche di Milano per l'anno* 1842, p. 57.

in many instances, and in both hemispheres, that there is an appreciable influence exerted by surrounding denser rocks, (basalt, greenstone, diorite, and melaphyre, in opposition to specifically lighter secondary and tertiary formations,) in the same manner as volcanic islands[21] influence gravity and augment its intensity. Many of the anomalies which presented themselves in these observations do not, however, admit of being explained by any visible geological characters of the soil.

For the southern hemisphere we possess a small number of admirable, but very widely diffused observations made by Freycinet, Duperrey, Fallows, Lütke, Brisbane and Rümker. These observations have confirmed a fact which had been strikingly demonstrated in the northern hemisphere, namely, that the intensity of gravity is not the same for all places having the same latitude, and that the increase of gravity from the equator towards the poles appears to be subjected to different laws under different meridians. Although the pendulum measurements made by Lacaille at the Cape of Good Hope, and those conducted in the Spanish circumnavigating expedition by Malaspina, may have led to the belief that the southern hemisphere is in general much more compressed than the northern, comparisons made between the Falkland Islands and New Holland on the one hand,

led to an error in the calculation, and had rendered a correction necessary as early as 1786, (when a somewhat obscure one was given by the Chevalier de Buat,) on account of the difference in the loss of weight of solid bodies, when they are either at rest in a fluid, or impelled in a vibratory motion. Bessel with his usual analytical clearness laid down the following axiom in his *Untersuchungen über die Länge des einfachen Secundenpendels*, s. 32, 63, 126—129. "When a body is moving in a fluid (the atmosphere), the latter belongs with it to the moved system, and the moving force must be distributed not only over the particles of the solid moved body, but also over all the moved particles of the fluid." On the experiments of Sabine and Baily, which originated in Bessel's practically important pendulum correction (reduction to a vacuum), see John Herschel in the *Memoir of Francis Baily*, 1845, pp. 17—21.

[21] *Cosmos*, vol. i, p. 159. Compare, for the phenomena occurring in islands, Sabine *Pend. Exper.* 1825, p. 237, and Lutke, *Obs. du Pendule invariable, exécutées de* 1826—1829, p. 241. This work contains a remarkable table, p. 239, on the nature of the rocks occurring at 16 pendulum stations, from Spitzbergen (79° 50′ N. Lat.) to Valparaiso (33° 2′ S. Lat.).

and New York, Dunkirk, and Barcelona on the other, have, however, by their more exact results shown that the contrary is the case, as I have already elsewhere indicated.[22]

From the above data, it follows that the pendulum (although it is by no means an unimportant instrument in geognostic observations, being as it were a sort of plummet cast into the deep and unseen strata of the earth) does not determine the form of our planet with the same exactitude as the measurement of a degree, or the movements of our satellite. The concentric, elliptical, and individually homogeneous strata, which increase in density according to certain functions of distance from the surface towards the centre of the earth, may give rise to local fluctuations in the intensity of gravity at individual points of the earth's surface, which differ according to the character, position, and density of the several points. If the conditions which produce these deviations are much more recent than the consolidation of the

[22] *Cosmos*, vol. i, p. 161. Eduard Schmidt (*Mathem. und Phys. Geographie*, Th. i, s. 394), has separated from a large number of the pendulum observations which were made on board the corvettes Descubierta and Atrevida, under the command of Malaspina, those thirteen stations which belong to the southern hemisphere, from which he obtained a mean compression of $\frac{1}{280.34}$. Mathieu obtained $\frac{1}{284.4}$ from a comparison of Lacaille's observations at the Cape of Good Hope and the Isle of France with Paris, but the iustruments of measurement used at that day did not afford the same certainty as we now obtain by the appliances of Borda and Kater, and the more modern methods of observation. The present would seem a fitting place to notice the beautiful experiments of Foucault, which afford so high a proof of the ingenuity of the inventor, and by which we obtain ocular evidence of the rotation of the earth on its axis by means of the pendulum, whose plane of vibration slowly rotates from east to west. (*Comptes rendus de l'Acad. des Sc., Séance du 3 Février*, 1851, t. xxxii, p. 135). Experiments for noticing the deviation towards the east in observations of falling bodies, dropped from church towers or into mines, as suggested by Benzenberg and Reich, require a very great height, whilst Foucault's apparatus makes the effects of the earth's rotation perceptible with a pendulum only six feet long. We must not confound the phenomena which may be explained by rotation (as, for instance, Richer's clock experiments at Cayenne, diurnal aberration, the deviation of projectiles, trade winds, etc.), with those that may at any time be produced by Foucault's apparatus, and of which the members of the *Academia del Cimento* appear to have had some idea, although they did not farther develope it (Antinori, in the *Comptes rendus*, t. xxxii, p. 635).

outer crust, the figure of the surface cannot be assumed to be locally modified by the internal motion of the fused masses. The difference of the results of pendulum measurements is however much too great to be ascribed at the present day to errors of observation. Even where a coincidence in the results, or an obvious regularity has been discovered by the various grouping and combination of the points of observation, the pendulum always gives a greater ellipticity (varying between the limits $\frac{1}{278}$ and $\frac{1}{290}$) than could have been deduced from the measurements of a degree.

If we take the ellipticity which, in accordance with Bessel's last determination, is now generally adopted, namely, $\frac{1}{299 \cdot 152}$, we shall find that the bulging[23] at the

[23] In Grecian antiquity two regions of the earth were designated as being characterised, in accordance with the prevalent opinions of the time, by remarkable protuberances of the surface, namely, the high north of Asia and the land lying under the equator. "The high and naked Scythian plains," says Hippocrates (*de Aëre et Aquis* § xix, p. 72, Littré), "without being crowned by mountains stretch far upward to the meridian of the Bear." A similar opinion had previously been ascribed to Empedocles (Plut. *de Plac. Philos.* ii, 8). Aristotle (*Meteor.* i, 1 a 15, p. 66, Ideler) says that the older meteorologists, according to whose opinions the sun "did not go under the earth, but passed round it," considered that the protuberances of the earth towards the north were the cause of the disappearance of the sun, or of the production of night. And in the compilation of the *Problems* (xxvi, 15, page 941, Bekker), the cold of the north wind was ascribed to the elevation of the soil in this region of the earth, and in all these passages there is no reference to mountains, but merely to a bulging of the earth into elevated plateaux. I have already elsewhere shown (*Asie Centrale*, t. i, p. 58) that Strabo, who alone makes use of the very characteristic word ὀροπέδια, says that the difference of climate which arises from geographical position must everywhere be distinguished from that which we ascribe to elevation above the sea, in Armenia (xi, p. 522, Casaub.), in Lycaonia, which is inhabited by wild asses (xii, p. 568), and in Upper India, in the auriferous country of the Derdi (xv, p. 706). "Even in southern parts of the world," says the geographer of Amasia, "every high district, if it be also a plain, is cold" (ii, p. 73). Eratosthenes and Polybius ascribe the very moderate temperature which prevails under the equator not only to the more rapid transit of the sun (Geminus, *Elem. Astron.* c. 13; Cleom. *Cycl. Theor.*, 1, 6), but more especially to the bulging of the earth (See my *Examen Crit. de la Géogr.* t. iii, pp. 150—152). Both maintain, according to the testimony of Strabo (ii, p. 97), "that the district lying immediately below the equator is the highest, on which account much rain falls there, in consequence of the very large accumulation of northern clouds at the period when

equator amounts to about 645,457 feet; about $11\frac{1}{5}$, or more accurately, 11.492 geographical miles. As a comparison has

those winds prevail, which change with the season of the year." Of these two opinions regarding the elevation of the land in Northern Asia (the Scythian Europe of Herodotus) and in the equatorial zone, the former of the two, with the pertinacity characteristic of error, has kept its ground for nearly two thousand years, and has given occasion to the geological myth of an uninterrupted plateau in the Tartar district lying to the north of the Himalayas, whilst the other opinion could only be justified in reference to a portion of Asia, lying beyond the tropical zone, and consequently applies only to the colossal, "elevated or mountain plateau, Meru," which is celebrated in the most ancient and noblest memorials of Indian poetry. (See Wilson's *Dict. Sanscrit and English*, 1832, p. 674, where the word *Meru* is explained to signify an elevated plateau). I have thought it necessary to enter thus circumstantially into this question, in order that I might refute the hypothesis of the intellectual Fréret, who, without indicating any passages from Greek writers, and merely alluding to one which seemed to treat of tropical rain, interprets the opinion advanced regarding bulgings of the soil as having reference to compression or elongation at the poles. In the *Mém. de l'Acad. des Inscriptions*, t. xviii, 1753, p. 112, Fréret expresses himself as follows:— "To explain the rains which prevailed in those equinoctial regions, which the conquests of Alexander first made known, it was supposed that there were currents which drove the clouds from the poles towards the equator, where, in default of mountains to stop their progress, they were arrested by the general elevation of the soil, whose surface at the equator is farther removed from the centre than under the poles. Some physicists have ascribed to the globe the figure of a spheroid, which bulges at the equator and is flattened towards the poles, while on the contrary, in the opinion of those of the ancients who believed that the earth was elongated towards the poles, the polar regions are farther removed than the equatorial zone from the centre of the earth." I can find no evidence in the works of the ancients to justify these assertions. In the third section of the first book of Strabo (page 48, Casaub.), it is expressly stated that, "after Eratosthenes has observed that the whole earth is spherical, although not like a sphere that has been made by a turning-lathe (an expression that is borrowed from Herodotus, iv. 36), and exhibits many deviations from this form, he adduces numerous modifications of shape which have been produced by the action of water and fire, by earthquakes, subterranean currents of wind (elastic vapours?), and other causes of the same kind, which, however, are not given in the order of their occurrence, for the rotundity of the entire earth results from the co-ordination of the whole, such modifications in no degree affecting the general form of our earth, the lesser vanishing in the greater." Subsequently we read, also in Groskurd's admirable translation, "that the earth, together with the sea, is spherical, the two constituting one and the same surface. The projection of the land, which is inconsiderable and may remain unnoticed is

quite three times as great as the elevation of the highest of our mountains above the sea's level, but it is almost five times as great as that of the eastern plateau of Thibet.

We ought here to observe that the results of the earth's compression, which have been obtained by mere measurements of a degree, or by combinations of the former with pendulum measurements, show far less [24] considerable differences in the amount of the equinoctial bulging than we should have been disposed at first sight to conclude from the fractional numbers. The difference of the polar compressions ($\frac{1}{310}$ and $\frac{1}{280}$) amounts to only about 7000 feet in the difference of the major and minor axes, basing the calculation on both extreme numerical limits; and this is not twice the elevation of the small mountains of the Brocken and of Vesuvius; the difference being only about one-tenth

[24] It has often seemed to me as if the amount of the compression of the earth was regarded as somewhat doubtful merely from our wish to attain an unnecessary degree of accuracy. If we take the values of the compression at $\frac{1}{310}$, $\frac{1}{300}$, $\frac{1}{290}$, $\frac{1}{280}$, we find that the difference of both radii is equal to 10,554, 10,905, 11,281, 11,684 toises, or 67,488, 69,554, 73,137, 74,714 feet. The fluctuation of 30 units in the denominator produces only a fluctuation of 1,130 toises or 7,126 feet in the polar radius, an amount which, when compared with the visible inequalities of the earth's surface appears so very inconsiderable, that I am often surprised to find that the experiments coincide within such closely approximating limits. Individual observations scattered over wide surfaces will indeed teach us little more than what we already know, but it would be of considerable importance to connect together all the measurements that have been made over the entire surface of Europe, including in this calculation all astronomically determined points." (Bessel, in a letter addressed to myself, December, 1828.) Even if this plan were carried out, we should then only know the form of that portion of the earth, which may be regarded as a peninsular projection, extending westward, about sixty-six and a half degrees from the great Asiatic Continent. The steppes of Northern Asia, even the middle Kirghis steppe, a considerable portion of which I have myself seen, are often interspersed with hills, and in respect to uninterrupted levels, cannot be compared with the Pampas of Buenos Ayres, or the Llanos of Venezuela. The latter, which are far removed from all mountain chains and consist immediately below the surface of secondary and tertiary strata, having a very uniform and low degree of density, might by differences in the results of pendulum vibrations, yield very decisive conclusions in reference to the local constitution of the deep internal strata of the earth. — Compare my *Views of Nature*, pp. 2—8, 29—32.

of the bulging which would be yielded by a polar compression of $\frac{1}{299}$.

As soon as it had been ascertained by more accurate measurements of a degree, made at very different latitudes, that the earth could not be uniformly dense in its interior, (because the results showed that the compression was very much less than had been assumed by Newton ($\frac{1}{230}$), and much greater than was supposed by Huygens ($\frac{1}{578}$), who considered that all forces of attraction were combined in the centre of the earth,) the connection between the amount of compression and the law of density in the interior of our earth necessarily became a very important object of analytical calculation. Theoretical speculations regarding gravity very early led to the consideration of the attraction of large mountain masses, which rise freely and precipitously into the atmosphere from the dried surface of our planet. Newton, in his *Treatise of the System of the World in a Popular Way*, 1728, endeavoured to determine what amount of deviation from the perpendicular direction the pendulum would experience from a mountain 2,665 feet in height and 5,330 feet in diameter. This consideration very probably gave occasion to the unsatisfactory experiments, which were made by Bouguer on Chimborazo,[25] by Maskelyne and

[25] Bouguer who had been induced by La Condamine to institute experiments on the deviation of the plummet near the mountain of Chimborazo, does not allude in his *Figure de la Terre*, pp. 364—394 to Newton's proposition. Unfortunately the most skilful of the two travellers did not observe on the east and western sides of the colossal mountain, having limited his experiments (December, 1738) to two stations lying on the same side of Chimborazo, first in a southerly direction 61° 30′ West, about 4,572 toises or 29,326 feet from the centre of the mountain, and then to the South 16° West (distance 1,753 toises or 11,210 feet). The first of these stations lay in a district with which I am well acquainted, and probably at the same elevation as the small alpine lake of Yana-cocha, and the other in the pumice-stone plain of the Arenal (La Condamine, *Voyage à l'Equateur*, pp. 68—70). The deviation yielded by the altitudes of the stars, was, contrary to all expectation, only 7.″5 which was ascribed by the observers themselves to the difficulty of making observations so immediately in the vicinity of the limit of perpetual snow, to the want of accuracy in their instruments, and above all to the great cavities which were conjectured to exist within this colossal trachytic mountain. I have already expressed many doubts, based upon geological grounds, as to this assumption of very large cavities, and of the very inconsiderable mass of the tra-

Hutton on Shehallien, near Blair-Athol, in Perthshire; to the comparison of pendulum lengths on a plain lying at an elevation of 6000 feet and at the level of the sea (as for instance Carlini's observations at the Hospice of Mont Cenis, and Biot and Mathieu's at Bordeaux); and lastly to the delicate and thoroughly decisive experiments undertaken in 1837 by Reich and Bailey with the ingeniously constructed torsion-balance which was invented by John Mitchell and subsequently given to Cavendish by Wollaston.[26] The three modes of determining the density of our planet (by vicinity to a mountain mass, elevation of a mountainous plateau, and the balance) have already been so circumstantially detailed in a former part of the *Cosmos* (vol. i, p. 158), that it only remains for us to notice the experiments given in Reich's new treatise, and prosecuted by that indefatigable observer during the interval between the years 1847 and 1850.[27]

chytic dome of Chimborazo. South-south-east of this mountain, near the Indian village of Calpi, lies the volcanic cone of Yana-urcu, which I carefully investigated in concert with Bonpland, and which is certainly of more recent origin then the elevation of the great dome-shaped trachytic mountain, in which neither I nor Boussingault could discover anything analogous to a crator. See the *Ascent of Chimborazo* in my *Kleine Schriften*, Bd. i, s. 138.

[26] Baily, *Exper. with the Torsion Rod for determining the mean density of the earth*, 1843, p. 6; John Herschel, *Memoir of Francis Baily*, 1845, p. 24.

[27] Reich, *Neue Versuche mit der Drehwage*, in the *Abhandl. der mathem. physischen Classe der Kön. Sächsischen Gesellschaft der Wissenschaften zu Leipzig*, 1852, Bd. i, s. 405, 418. The most recent experiments of my respected friend Professor Reich, approximate somewhat more closely to the results given in Baily's admirable work. I have obtained the mean 5.5772 from the whole series of experiments: (a) with the tin ball and the longer thicker copper wire, the result was 5.5712, with a probable error of 0.0113; (b) with the tin ball, and with the shorter thinner copper wire, as well as with the tin ball and the bi-filar iron wire, 5.5832, with a probable error of 0.0149. Taking this error into account, the mean in (a) and (b) is 5.5756. The result obtained by Baily, and which was certainly deduced from a larger number of experiments (5.660), might indeed give us a somewhat higher density, as it obviously rose in proportion to the greater lightness of the balls that were used in the experiments, which were either of glass or ivory. (Reich in Poggend. *Annalen*, Bd. lxxxv, s. 190. Compare also Whitehead Hearn in the *Philos. Transact. for* 1847, pp. 217—229.) The motion of the torsion balance was observed by Baily by means of the reflection of a scale obtained from a mirror, which was attached to the middle of the

"Carte de l'intensité magnétique horizontale entre Paris et Naples," in the *Mém. de l'Acad. de Bruxelles*, t. xiv; the observations of Forbes in Germany, Flanders, and Italy in 1832 and 1837 (*Transact. of the Royal Soc. of Edinburgh*, vol. xv, p. 27); the extremely accurate observations of Rudberg in France, Germany, and Sweden, 1832; the observations of Dr. Bache (Director of the Coasts' Survey of the United States), 1837 and 1840, at 21 stations both in reference to inclination and intensity.

1806—1807. A long series of observations at Berlin on the horary variations of declination and the recurrence of magnetic storms (perturbations) by Humboldt and Oltmanns mainly at the periods of the solstices and equinoxes for 5 and 6, or even sometimes 9 days, and as many nights consecutively, by means of Prony's magnetic telescope which allowed arcs of 7 or 8 seconds to be distinguished.

1812. Morichini, of Rome, maintained that non-magnetic steel-needles become magnetic by contact with the violet rays of light. Regarding the long contention excited by this assertion and the ingenious experiments of Mrs. Somerville, together with the wholly negative results of Riess and Moser, see Sir David Brewster, *Treatise on Magnetism*, 1837, p. 48.

1815—1818. }
1823—1826. } The two circumnavigation voyages of Otto von Kotzebue, the first in the Ruric, the second, five years later, in the Predprijatie.

1817—1848. The series of great scientific maritime expeditions equipped by the French Government, and which yielded such rich results to our knowledge of terrestrial magnetism; beginning with Freycinet's voyage in the corvette Uranie 1817—1820, and followed by Duperrey in the frigate La Coquille 1822—1825, Bougainville in the frigate Thetis 1824—1826, Dumont d'Urville in the Astrolabe 1826—1829, and to the south pole in the Zélée 1837—1840, Jules De Blosseville to India 1828 (Herbert *Asiat. Researches*, vol. xviii, p. 4, Humboldt, *Asie Cent.* t. iii, p. 468), and to Iceland 1833, (Lottin, *Voy. de la Recherche* 1836, pp. 376—409), du Petit Thouars with Tessan in the Venus 1837—1839, le Vaillant in the Bonite 1836—1837, the voyage of the "Commission scientifique du Nord" (Lottin,

Bravais, Martins, Siljeström) to Scandinavia, Lapland, the Faroe Islands, and Spitzbergen in the corvette la Recherche 1835—1840, Bérard to the Gulf of Mexico and North America 1838, to the Cape of Good Hope and St. Helena 1842 and 1846 (Sabine in the *Phil. Transact. for* 1849, pt. ii, p. 175), and Francis de Castlenau, *Voy. dans les parties centrales de l'Amérique du Sud* 1847—1850.

1818—1851. The series of important and adventurous expeditions in the Arctic Polar Seas through the instrumentality of the British Government first suggested by the praiseworthy zeal of John Barrow; Edward Sabine's magnetic and astronomical observations in Sir John Ross's voyage to Davis Straits, Baffin's Bay, and Lancaster Sound in 1818, as well as in Parry's voyage in the Hecla and Griper through Barrow Straits to Melville Island 1819—1820; Franklin, Richardson, and Back 1819—1822, and again from 1825—1827, Back alone from 1833—1835, when almost the only food that the expedition could obtain for weeks together was a lichen, *Gyrophora pustulata*, the "Tripe de Roche" of the Canadian hunters, which has been chemically analyzed by John Stenhouse in the *Phil. Transact. for* 1849, pt. ii, p. 393; Parry's second expedition with Lyon in the Fury and Hecla 1821—1823; Parry's third voyage with James Ross 1824—1825; Parry's fourth voyage when he attempted with Lieutenants Foster and Crozier to penetrate northward from Spitsbergen on the ice in 1827, when they reached the latitude 82° 45′; John Ross, together with his accomplished nephew James Ross, in a second voyage undertaken at the expense of Felix Booth, and which was rendered the more perilous on account of protracted detention in the ice, namely from 1829 to 1833; Dease and Simpson of the Hudson's Bay Company 1838—1839; and more recently, in search of Sir John Franklin, the expeditions of Captains Ommanney, Austin, Penny, Sir John Ross, and Phillips 1850 and 1851. The expedition of Captain Penny reached the northern latitude of 77° 6′ Victoria Channel into which Wellington Channel opens.

1819—1821. Bellinghausen's voyage into the Antarctic Ocean.

1819. The appearance of the great work of Hansteen *On the Magnetism of the Earth*, which, however, was completed

as early as 1813. This work has exercised an undoubted influence on the encouragement and better direction of geomagnetic studies, and it was followed by the author's general charts of the curves of equal inclination and intensity for a considerable part of the earth's surface.

1819. The observations of Admirals Roussin and Givry on the Brazilian coasts between the mouths of the rivers Marañon and La Plata.

1819—1820. Oersted made the great discovery of the fact that a conductor that is being traversed by a closed electric current, exerts a definite action upon the direction of the magnetic needle according to their relative positions, and as long as the current continues uninterrupted. The earliest extension of this discovery (together with that of the exhibition of metals from the alkalies and that of the two kinds of polarization of light—probably the most brilliant discovery of the century—)[69] was due to Arago's observation, that a wire, through which an electrical current is passing, even when made of copper or platinum, attracts and holds fast iron filings like a magnet, and that needles introduced into the interior of a galvanic helix become alternately charged by the opposite magnetic poles in accordance with the reversed direction of the coils (*Ann. de Chim. et de Phys.*, t. xv, p. 93). The discovery of these phenomena, which were exhibited under the most varied modifications, was followed by Ampere's ingenious theoretical combinations regarding the alternating electro-magnetic actions of the molecules of ponderable bodies. These combinations were confirmed by a series of new and highly ingenious instruments, and led to a knowledge of the laws of many hitherto apparently contradictory phenomena of magnetism.

1820—1824. Ferdinand von Wrangel's and Anjou's expedition to the north coasts of Siberia and to the Frozen Ocean. (Important phenomena of polar light, see th. ii, s. 259.)

1820. Scoresby's Account of the Arctic Regions; experiments of magnetic intensity, vol. ii, p. 537—554.

1821. Seebeck's discovery of thermo-magnetism and

[69] Malus's (1808) and Arago's (1811) ordinary and chromatic polarization of Light. See *Cosmos*, vol. ii, p. 715.

thermo-electricity. The contact of two unequally warmed metals (especially bismuth and copper) or differences of temperature in the individual parts of a homogeneous metallic ring, were recognised as sources of the production of magneto-electric currents.

1821—1823. Weddell's voyage into the Antarctic Ocean as far as lat. 74° 15′.

1822—1823. Sabine's two important expeditions for the accurate determination of the magnetic intensity and the length of the pendulum in different latitudes (from the east coasts of Africa to the equator, Brazil, Havannah, Greenland as far as lat. 74° 32′, Norway and Spitzbergen in lat. 79° 50′). The results of these very comprehensive operations were first published in 1824 under the title of *Account of Experiments to determine the Figure of the Earth*, pp. 460—509.

1824. Erikson's Magnetic Observations along the shores of the Baltic.

1825. Arago discovers *Magnetism of Rotation*. The first suggestion that led to this unexpected discovery was afforded by his observation on the side of the hill in Greenwich Park of the decrease in the duration of the oscillations of an inclination needle by the action of neighbouring non-magnetic substances. In Arago's rotation experiments, the oscillations of the needle were affected by water, ice, glass, charcoal, and mercury.[70]

1825—1827. Magnetic Observations by Boussingault in different parts of South America (Marmato, Quito).

1826—1827. Observations of Intensity by Keilhau at 20 stations (in Finmark, Spitzbergen, and Bear Island), by Keilhau and Boeck in Southern Germany and Italy (Schum. *Astr. Nachr.* No. 146).

1826—1829. Admiral Lütke's voyage round the world; the magnetic part was most carefully prepared in 1834 by Lenz (see *Partie Nautique du Voyage*, 1836).

1826—1830. Captain Philip Parker King's Observations in the southern portions of the eastern and western coasts of South America (Brazil, Monte Video, the Straits of Magellan, Chili, and Valparaiso).

1827—1839. Quetelet, *Etat du Magnétisme Terrestre*

[70] *Cosmos*, vol. i, p. 172.

(*Bruxelles*) *pendant douze années*. Very accurate observations.

1827. Sabine, On the determination of the relative intensity of the magnetic terrestrial force in Paris and London. An analogous comparison between Paris and Christiana was made by Hansteen in 1825—1828 (*Meeting of the British Association at Liverpool* 1837, pp. 19—23). The many results of intensity, which had been obtained by French, English, and Scandinavian travellers, now first admitted of being brought into numerical connection with oscillating needles, which had been compared together at the three above-named cities. These numbers which could therefore now be established as relative values were found to be for Paris 1.348, as determined by myself, for London 1.372 by Sabine, and for Christiana 1.423 by Hansteen. They all refer to the intensity of the magnetic force at one point of the magnetic equator (the curve of no inclination) which intersects the Peruvian Cordilleras between Micuipampa and Caxamarca, in south latitude 7° 2′ and western longitude 78° 48′, where the intensity was assumed by myself as = 1.000. This assumed standard (Humboldt, *Recueil d'Observ. Astr.* vol. ii, p. 382—385, and *Voyage aux Régions Equin.*, t. iii, p. 622) formed the basis, for forty years, of the reductions given in all tables of intensity (Gay-Lussac in the *Mém. de la Société d'Arcueil*, t. i. 1807, p. 21; Hansteen, *On the Magnetism of the Earth*, 1819, p. 71; Sabine, in the *Rep. of the British Association at Liverpool*, pp. 43—58). It has, however, in recent times been justly objected to on account of its want of general applicability, because the line of no inclination[71] does not connect together

[71] "Before the practice was adopted of determining *absolute values*, the most generally used scale (and which still continues to be very frequently referred to), was founded on the time of vibration, observed by Mr. de Humboldt, about the commencement of the present century, at a station in the Andes of South America, where the direction of the dipping needle was horizontal, a condition which was for some time erroneously supposed to be an indication of the minimum of magnetic force at the earth's surface. From a comparison of the times of vibration of Mr. de Humboldt's needle in South America and in Paris, the ratio of the magnetic force at Paris to what was supposed to be its minimum was inferred (1.348), and from the results so obtained, combined with a similar comparison made by myself between Paris and London, in 1827, with several magnets, the ratio of the force in London to that of Mr.

the points of feeblest intensity (Sabine, in the *Phil. Transact. for* 1846, pt. iii, p. 254, and in the *Manual of Scient. Inquiry for the use of the British Navy*, 1849, p. 17).

1828—1829. The voyage of Hansteen and Due: Magnetic observations in European Russia and in Eastern Siberia as far as Irkutsk.

1828—1830. Adolf Erman's voyage of circumnavigation, with his journey through Northern Asia, and his passage across both oceans, in the Russian frigate Krotkoi. The identity of the instruments employed, the uniformity of the methods and the exactness of the astronomical determinations of position will impart a permanent scientific reputation to this expedition, which was equipped at the expense of a private individual, and conducted by a thoroughly well-informed and skilful observer. See the *general declination Chart*, based upon Erman's observations in *the Report of the Committee relat. to the Arctic Expedition*, 1840, pl. 3.

1828—1829. Humboldt's continuation of the observations begun in 1800 and 1807, at the time of the solstices and equinoxes regarding horary declination and the epochs of extraordinary perturbations, carried on in a magnetic pavilion specially erected for the purpose at Berlin, and provided with one of Gambey's compasses. Corresponding measurements were made at St. Petersburgh, Nikolajew, and in the mines of Freiberg, by Professor Reich, 227 feet below the surface of the soil. Dove and Riess continued these observations in reference to the variation and intensity of the horizontal magnetic force till November 1830 (Poggend. *Annalen*. Bd. xv, s. 318—336; Bd. xix, s. 375—391, with 16 tab.; Bd. xx, s. 545—555).

1829—1834. The botanist David Douglas, who met his death in Owhyhee, by falling into a trap in which a wild bull had previously been caught, made an admirable series of

de Humboldt's original station in South America has been inferred to be 1.372 to 1.000. This is the origin of the number 1.372, which has been generally employed by British observers. By *absolute* measurements we are not only enabled to compare numerically with one another the results of experiments made in the most distant parts of the globe, with apparatus not previously compared, but we also furnish the means of comparing hereafter the intensity which exists at the present epoch, with that which may be found at future periods." Sabine, in the *Manual for the use of the British Navy*, 1849, p. 17.

observations on declination and intensity along the north-west coast of America, and upon the Sandwich Islands as far as the margin of the crater of Kiraueah (Sabine, *Rep. of the Meeting of the British Association at Liverpool*, pp. 27—32).

1829. Kupffer, *Voyage au Mont Elbrouz dans le Caucase*, pp. 68—115.

1829. Humboldt's magnetic observations on terrestrial magnetism with the simultaneous astronomical determinations of position in an expedition in Northern Asia undertaken by command of the Emperor Nicholas, between the longitudes 11° 3′ and 80° 12′ east of Paris, near the Lake Dzaisan as well as between the latitudes of 45° 43′ (the island of Birutschicassa in the Caspian Sea) to 58° 52′ in the northern parts of the Ural district near Werchoturie (*Asie Centrale*, t. iii, pp. 440—478).

1829. The Imperial Academy of Sciences at St. Petersburgh, acceded to Humboldt's suggestion for the establishment of magnetic and meteorological stations in the different climatic zones of European and Asiatic Russia, as well as for the erection of a physical central observatory in the capital of the empire under the efficient scientific direction of Professor Kupffer. (See *Cosmos*, vol. i, p. 184. Kupffer *Rapport adressé à l'Acad. de St. Pétersbourg relatif à l'Observatoire physique central, fondé auprès du Corps des Mines*, in Schum. *Astr. Nachr.* No. 726; and in his *Annales Magnétiques*, p. xi.) Through the continued patronage, which the Finance Minister, Count Cancrin, has awarded to every great scientific undertaking, a portion of the simultaneously corresponding observations[72] between the White Sea and

[72] The first idea of the utility of a systematic and simultaneously conducted series of magnetic observations is due to Celsius, and, without referring to the discovery and measurement of the influence of polar light on magnetic variation, which was, in fact, due to his assistant, Olav Hiörter (March, 1741), we may mention that he was the means of inducing Graham, in the summer of 1741, to join him in his investigations for discovering whether certain extraordinary perturbations, which had from time to time exerted a horary influence on the course of the magnetic needle at Upsala had also been observed at the same time by him in London. A simultaneity in the perturbations afforded a proof, he said, that the cause of these disturbances is extended over considerable portions of the earth's surface, and is not dependent upon accidental local actions (Celsius, in *Svenska Veten-*

the Crimea, and between the Gulf of Finland and the shores of the Pacific in Russian America, were begun as early as 1832. A permanent magnetic station was established in the old monastery at Pekin, which, from time to time since the reign of Peter the Great, has been inhabited by monks of the Greek Church. The learned astronomer, Fuss, who took the principal part in the measurements for the determination of the difference of level between the Caspian and the Black Sea was chosen to arrange the first magnetic establishments in China. At a subsequent period Kupffer in his voyage of circumnavigation compared together all the instruments that had been employed in the magnetic and meteorological stations as far east as Nertschinsk in 119° 36′ longitude, and with the fundamental standards. The magnetic observations of Fedorow, in Siberia, which are no doubt highly valuable, are still unpublished.

1830—1845. Colonel Graham of the topographical engineers of the United States, made observations on the magnetic intensity at the southern boundary of Canada (*Phil. Transact. for* 1846, pt. iii, p. 242).

1830. Fuss, Magnetic, Astronomical, and Hypsometrical Observations on the journey from the Lake of Baikal, through Ergi-Oude, Durma, and the Gobi, which lies at an elevation of only 2525 feet, to Pekin, in order to establish the magnetic and meteorological observatory in that city, where Kovanko continued for 10 years to prosecute his observations (*Rep. of the Seventh Meeting of the Brit. Assoc.* 1837, pp. 497—499; and Humboldt, *Asie Centrale*, t. i, p. 8; t. ii, p. 141; t. iii, pp. 468, 477).

1831—1836. Captain Fitzroy in his voyage round the world in the Beagle, as well as in the survey of the coasts of the most southern portions of America, with a Gam-

skaps Academiens Handlingar för 1740, p. 44; Hiörter, *op. cit.* 1747, p. 27). As Arago had recognised that the magnetic perturbations owing to polar light are diffused over districts, in which the phenomena of light which accompany magnetic storms have not been seen, he devised a plan, by which he was enabled to carry on simultaneous horary observations (in 1823) with our common friend Kupffer, at Kasan, which lies almost 47° east of Paris. Similar simultaneous observations of declination were begun in 1828 by myself, in conjunction with Arago and Reich, at Berlin, Paris, and Freiberg (see Poggend. *Annalen*, Bd. xix, s. 337).

British magnetic stations this opposition and the periodicity of the horary variation in the dip have been firmly established by several thousand regularly prosecuted observations, which have all been submitted to a careful discussion since 1840. The present would seem the most fitting place to notice the facts that have been obtained as materials on which to base a general theory of terrestrial magnetism. It must, however, first be observed, that if we consider the periodical variations which are recognised in the three elements of terrestrial magnetism, we must, with Sabine, distinguish in the turning hours at which the maxima or minima occur, two greater, and therefore more important, extremes, and other slight variations, which seem to be intercalated amongst the others, as it were, and which are for the most part of an irregular character. The recurring movements of the horizontal and dipping needles, as well as the variation in the intensity of the total force, consequently present principal and secondary maxima or minima, and generally some of either type, which therefore constitutes a double progression with four turning hours (the ordinary case), and a simple progression with two turning hours, that is to say, with a single maximum and a single minimum. Thus, for instance, in Van Diemen's Land, the intensity or total force exhibits a simple progression, combined with a

was greater in the evening than towards morning. At Greenwich the principal maximum of the horizontal force was about 6 P.M., the principal minimum about 10 A.M. or at noon; at Schulzendorf, near Berlin, the maximum falls at 8 P.M., the minimum at 9 A.M.; at St. Petersburg the max. falls at 8 P.M., the min. at 11h. 20m. A.M.; at Toronto the max. falls at 4 P.M., the min. at 11 A.M. The time is always reckoned according to the true time of the respective places (Airy, *Magn. Observ. at Greenwich for* 1845, p. 13; *for* 1846, p. 102; *for* 1847, p. 241; Riess and Moser, in Poggend. *Annalen.* Bd. xix, 1830, s. 175; Kupffer, *Compte rendu Annuel de l'Observatoire Centrale Magn. de St. Pétersb.* 1852, p. 28; and Sabine, *Magn. Observ. at Toronto,* vol. i, 1840—1842, p. xlii). The turning hours at the Cape of Good Hope and at St. Helena, where the horizontal force is the weakest in the evening, seem to be singularly at variance, and almost the very opposite of one another (Sabine, *Magn. Obs. at the Cape of Good Hope,* p. xl, *at St. Helena,* p. 40). Such, however, is not the case further eastward, in other parts of the great southern hemisphere. "The principal feature in the diurnal change of the *horizontal* force at Hobarton is the decrease of force in the forenoon and its subsequent increase in the afternoon" (Sabine, *Magn. Obs. at Hobarton,* vol. i, p. liv. vol. ii, p. xliii).

shown by Wahlenberg and Erman the elder, in the averages of the summer and winter months. But in accordance with the criterion here indicated, a spring in one zone must be denominated warm, which hardly attains the seventh or eighth part of temperature of one which in another zone, near the equator, will be called cold. I may mention the differences between the average temperature of St. Petersburg (38°.12 F.) and of the shores of the Orinoco. The purest spring water which I drank in the vicinity of the cataracts of Atures[31] and Maypures (81°.14 F.) or in the forest of Atabapo, had a temperature of more than 79° F.; even the temperature of the great rivers in tropical South America, corresponds with the high degrees of heat of such cold[32] springs.

[31] Humboldt, *Voyage aux Régions Equinoxiales*, t. ii, p. 376.

[32] For the sake of comparing the temperature of springs where they break forth directly from the earth, with that of large rivers flowing through open channels, I here bring together the following average numbers from my journals:—

Rio Apure, lat. 7¾°; temperature, 81°.

Orinoco, between 4° and 8° of latitude; 81°.5—85°.3.

Springs in the forest, near the cataract of Maypures, breaking forth from the granite, 82°.

Cassiquiare, the branch of the Upper Orinoco, which forms the union with the Amazon; only 75°.7.

Rio Negro, above San Carlos (scarcely 1° 53′ to the north of the equator); only 74°.8.

Rio Atabapo, 79°.2 (lat. 3° 50′).

Orinoco, near the entrance of the Atabapo, 82°.

Rio Grande de la Magdalena (lat. 5° 12′ to 9° 56′), 79° 9′.

Amazon, 5° 31′ south latitude, opposite to the Pongo of Rentema (Provincia Jaen de Bracamoros), scarcely 1300 feet above the South Sea, only 72°.5.

The great mass of water of the Orinoco consequently approaches the average temperature of the air of the vicinity. During great inundations of the Savannahs, the yellowish brown waters, which smell of sulphuretted hydrogen, acquire a temperature of 92°.8; this I found to be the temperature in the *Lagartero*, to the east of Guayaquil, which swarmed with crocodiles. The soil there becomes heated, as in shallow rivers, by the warmth produced in it by the sun's rays falling upon it. With regard to the multifarious causes of the low temperature of the water of the Rio Negro, which is of a *coffee-brown* colour by reflected light, and of the *white* waters of the Cassiquiare (a constantly clouded sky, the quantity of rain, the evaporation from the dense forests, and

The breaking out of springs, effected by multifarious causes of pressure and by the communication of fissures containing water, is such a universal phenomenon of the surface of the earth, that waters flow forth at some points from the most elevated mountain strata, and at others from the bottom of the sea. In the first quarter of this century numerous results were collected by Leopold von Buch, Wahlenberg and myself, with regard to the temperature of springs and the diffusion of heat in the interior of the earth in both hemispheres, from 12° S. lat. to 71° N.[33] The springs which have an unchangeable temperature were carefully separated from those which vary with the seasons; and Leopold von Buch ascertained the powerful influence of the distribution of rain in the course of the year, that is to say, the influence of the proportion between the relative abundance of winter and summer rain upon the temperature of the variable springs, which, as regards number, are the most widely distributed. More recently[34] some very ingenious

the want of hot sandy tracts upon the banks), see my river voyage, in the *Rélation Historique*, t. ii, pp. 463 and 509. In the Rio Guancabamba or Chamaya, which falls into the Amazon, near the Pongo de Rentema, I found the temperature of the water to be only 67°.6, as its waters come with prodigious swiftness from the elevated lake Simicocha on the Cordillera. On my voyage of 52 days up the river Magdalena, from Mahates to Honda, I perceived most distinctly, from numerous observations, that a rise in the level of the water was indicated for hours previously by a diminution of the temperature of the river. The refrigeration of the stream occurred before the cold mountain waters from the Paramos near the source came down. Heat and water move, so to speak, in opposite directions and with very unequal velocities. When the water near Badillas rose suddenly, the temperature fell long before from 80°.6 to 74°.3. As, during the night, when one is established upon a low sandy islet, or upon the bank, with bag and baggage, a rapid rise of the river may be dangerous, the discovery of a prognostic of the approaching rise (the *avenida*) is of some importance.

[33] Leopold von Buch, *Physicalische Beschreibung der canarischen Inseln*, s. 8: Poggend. *Annalen*, Bd. xii, s. 403; *Bibliothèque Britannique, Sciences et Arts*, t. xix, 1802, p. 263; Wahlenberg, *De Veget. et Clim. in Helvetia Septentrionali Observatis*, pp. lxxviii and lxxxiv; Wahlenberg, *Flora Carpathica*, p. xciv, and in Gilbert's *Annalen*, Bd. xli, s. 115; Humboldt, in the *Mém. de la Soc. d'Arcueil*, t. iii (1817) p. 599.

[34] De Gasparin, in the *Bibliothèque Univ. Sciences et Arts*, t. xxxviii, 1828, pp. 54, 113 and 264; *Mém. de la Soc. Centrale d'Agriculture*,

comparative observations by De Gasparin, Schouw and Thurmann have thrown considerable light, in a geographical and hypsometrical point of view, in accordance with latitude and elevation upon this influence. Wahlenberg asserted that in very high latitudes the average temperature of variable springs is rather higher than that of the atmosphere; he sought the cause of this, not in the dryness of a very cold atmosphere and in the less abundant winter rain caused thereby, but in the snowy covering diminishing the radiation of heat from the soil. In those parts of the plain of Northern Asia, in which a perpetual icy stratum, or at least a frozen alluvial soil mixed with fragments of ice is found at a depth of a few feet,[35] the temperature of springs can only be employed with great caution for the investigation of Kupffer's important theory of the isogeothermal lines. A two-fold radiation of heat is then produced in the upper stratum of the earth: one upwards towards the atmosphere, and another downwards towards the icy stratum. A long series of valuable observations made by my friend and companion, Gustav Rose, during our Siberian expedition in the heat of summer (often in springs still surrounded by ice) between the Irtysch, the Obi, and the Caspian Sea, revealed a great complication of local disturbances. Those which present themselves from perfectly different causes in the tropical zone, in places where

1826, p. 178; Schouw, *Tableau du Climat et de la Végétation de l'Italie* vol. i, 1839, pp. 133—195; Thurmann, *Sur la température des sources de la chaîne du Jura, comparée à celle des sources de la plaine Suisse, des Alpes et des Vosges*, in the *Annuaire Météorologique de la France*, 1850, pp. 258—268. As regards the frequency of the summer and autumn rains, De Gasparin divides Europe into two strongly contrasted regions. Valuable materials are contained in Kämtz, *Lehrbuch der Meteorologie*, Bd. i, s. 448—506. According to Dove (Poggend. *Annalen*, Bd. xxxv, s. 376) in Italy, "at places to the north of which a chain of mountains is situated, the maxima of the curves of monthly quantities of rain fall in March and September; and where the mountains lie to the south, in April and October." The totality of the proportions of rain in the temperate zones may be comprehended under the following general point of view:—"The period of winter rain in the borders of the tropics constantly divides, the further we depart from these, into two maxima united by slighter falls, and these again unite into a summer-maximum in Germany; where, therefore, a temporary want of rain ceases altogether." See the section "Geothermik" in the excellent *Lehrbuch der Geognosie*, by Naumann, Bd. i, (1850), s. 41—73.

[35] See above, p. 45.

mountain springs burst forth upon vast elevated plateaux, eight or ten thousand feet above the sea (Micuipampa, Quito, Bogota), or in narrow, isolated mountain-peaks many thousand feet higher, not only include a far greater part of the surface of the earth, but also lead to the consideration of analogous thermic conditions in the mountainous countries of the temperate zones.

In this important subject it is above all things necessary to separate the cycle of actual observations from the theoretical conclusions which are founded upon them. What we seek, expressed in the most general way, is of a triple nature: —the distribution of heat in the crust of the earth which is accessible to us, in the aqueous covering (the ocean) and in the atmosphere. In the two envelopes of the body of the earth, the liquid and gaseous, an opposite alteration of temperature (diminution and increase in the superposed strata) prevails in a vertical direction. In the solid parts of the body of the earth the temperature increases with the depth; the alteration is in the same direction, although in a very different proportion, as in the aerial ocean, the shallows and rocks of which are formed by the elevated plateaux and multiform mountain peaks. We are most exactly acquainted by direct experiments, with the distribution of heat in the atmosphere,—geographically by local determination in latitude and longitude, and in accordance with hypsometric relations in proportion to the vertical elevation above the surface of the sea,—but in both cases almost exclusively in close contact with the solid and fluid parts of the surface of our planet. Scientific and systematically arranged investigations by aerostatic voyages in the free aerial ocean, beyond the near action of the earth, are still very rare, and therefore but little adapted to furnish the numerical data of average conditions which are so necessary. Upon the decrease of heat in the depths of the ocean observations are not wanting; but currents, which bring in water of different latitudes, depths, and densities, prevent the attainment of general results, almost to a greater extent than currents in the atmosphere. We have here touched preliminarily upon the thermic conditions of the envelopes of our planet, which will be treated of in detail hereafter, in order to consider the influence of the vertical distribution of heat in the solid

crust of the earth, and the system of the geo-isothermic lines, not in too isolated a condition, but as a part of the all-penetrating motion of heat, a truly cosmical activity.

Instructive as are, in many respects, observations upon the unequal diminution of temperature of springs which do not vary with the seasons as the height of their point of emergence increases,—still the local law of such a diminishing temperature of springs cannot be regarded, as is often done, as a universal geothermic law. If we were certain that waters flowed unmixed in a horizontal stratum of great extent, we might certainly suppose that they have gradually acquired the temperature of the solid ground, but in the great network of fissures of elevated masses, this case can rarely occur. Colder and more elevated waters mix with the lower ones. Our mining operations, inconsiderable as may be the depth to which they attain, are very instructive in this respect; but we should only obtain a direct knowledge of the isogeothermal lines, if thermometers were buried, according to Boussingault's method,[36] to a depth below that affected by the influences of the changes of temperature of the neighbouring atmosphere, and at very different elevations above the sea. From the forty-fifth degree of latitude to the parts of the tropical regions in the vicinity of the equator, the depth at which the stratum of invariable temperature commences, diminishes from 60 to 1½ or 2 feet. Burying the geothermometer at a small depth in order to obtain a knowledge of the average temperature of the earth, is therefore readily practicable only between the tropics or in the subtropical zone. The excellent expedient of Artesian wells which have indicated an increase of heat of 1° F. for every 54 to 58 feet in absolute depths of from 745 to 2345 feet has hitherto only been afforded to the physicist in districts not much more than 1600 feet above the level of the sea[37] I have visited silver-mines in the chain of the Andes, 6°45′ south of the equator at an elevation of nearly 13,200 feet and found the temperature of the water penetrating through the fissures of the limestone to be 52°.3 F.[38] The waters which were heated in the baths of the Inca

[36] See *Cosmos*, vol. i, p. 218, and vol. v, p. 40, Bohn's edition.

[37] See above, p. 37.

[38] Mina de Guadalupe, one of the Minas de Chota, *l.c. sup.* p. 41.

Tupac Yupanqui, upon the ridge of the Andes (*Paso del Assuay*), probably come from springs of the *Ladera de Cadlud*, where I have traced their course, near which the old Peruvian causeway also ran, barometrically to an elevation of 15,526 feet (almost that of Mont Blanc).[39] These are the highest points at which I could observe spring water in South America. In Europe the brothers Schlagintweit have found gallery-water in the gold mine in the Eastern Alps at a height of 9442 feet, and found that the temperature of small springs near the opening of the gallery of only 33°.4 F.,[40] at a distance from any snow or glacier ice. The highest limits of springs are very different according to geographical latitude, the elevation of the snow line and the relation of the highest peaks to the mountain ridges and plateaux.

If the radius of our planet were to be increased by the height of the Himalaya at the Kintschindjunga, and therefore uniformly over the whole surface by 28,175 feet (4.34 English miles), with this small increase of only $\frac{1}{800}$th of the radius, the heat in the surface cooled by radiation, would be (according to Fourier's analytical theory), almost the same as it now is in the upper crust of the earth. But if individual parts of the surface raise themselves in mountain chains and narrow peaks, like rocks upon the bottom of the aerial ocean, a diminution of heat takes place in the interior of the elevated strata, and this is modified by contact with strata of air of different temperature, by the capacity for heat and conductive power of heterogeneous kinds of rocks, by the sun's action on the forest-clad summits and declivities, by the greater and less radiation of the mountains in accordance with their form (relief), their massiveness) or their conical and pyramidal narrowness. The special elevations of the region of clouds, the snow and ice-coverings at various elevations of the snow line, and the frequency of the cool currents of air coming down the steep declivities, at particular times of the day, alter the effect of the terrestrial radiation. In proportion as the towering cones of the summits become cooled, a weak current

[39] Humboldt, *Views of Nature*, p. 393.

[40] Mine on the Great Fleuss in the Moll Valley of the Tauern, see Hermann and Adolph Schlagintweit, *Untersuchungen über die physikalische Geographie der Alpen*, 1850, s. 242—273.

has acquired a high temperature at a lower point under great pressure of accumulated vapours, being forced upwards, and thus coming under a pressure which does not correspond with its temperature. In this way "the Geysirs are natural collectors of steam power."

Of the hot springs a few approach nearly to absolute purity; others contain solutions of 8—12 parts of solid or gaseous matters. Among the former are the baths of Luxeueil, Pfeffer, and Gastein, the efficacy of which may appear so mysterious on account of their purity.[51] As all springs are fed principally by meteoric water, they contain nitrogen, as Boussingault has proved in the very pure[52] springs flowing from the granite in las Trincheras de Portocabello, and Bunsen[53] in the Cornelius spring at Aix and in the Geysir of Iceland. The organic matter dissolved in many springs also contains nitrogen, and is even sometimes bituminous. Until it was known from the experiments of Gay-Lussac and myself that rain and snow-water contain more oxygen than the atmosphere (the former 10, and the latter at least 8 per cent. more) it appeared very remarkable that a gaseous mixture, rich in oxygen, could be evolved from the springs of Nocera in the Apennines. The analyses made by Gay-Lussac during our stay at this mountain spring showed that it only contained as much oxygen as might have been furnished to it by atmospheric moisture.[54] If we be astonished at the

[51] Trommsdorf finds in the springs of Gastein only 0.303 of solid constituents in 1000 parts; Löwig, 0.291 in Pfeffer; and Longchamp only 0.236 in Luxeuil; on the other hand, 0.478 were found in 1000 parts of common well water in Berne; 5.459 in the Carlsbad bubbling spring; and even 7.454 in Wiesbaden (Studer, *Physikal. Geographie und Geologie*, ed. 2, 1847, cap. i, s. 92).

[52] "The hot springs which gush from the *granite* of the Cordillera of the coast (of Venezuela), are *nearly pure*; they only contain a small quantity of silica in solution, and hydrosulphuric acid gas, mixed with a little *nitrogen*. Their composition is identical with that which would result from the action of water upon sulphuret of silicium" (*Annales de Chimie et de Physique*, t. lii, 1833, p. 189). Upon the great quantity of nitrogen which is contained in the hot spring of Orense (154°.4), see Maria Rubio, *Tratado de las Fuentes Minerales de España*, 1853, p. 331.

[53] Sartorius von Waltershausen, *Skizze von Island*, s. 125.

[54] The distinguished chemist Morechini of Rome, had stated the oxygen contained in the spring of Nocera (situated 2240 feet above the sea) to be 0.40; Gay-Lussac (26 September, 1805) found the exact

silicious deposits as a constructive material of which nature, as it were, artificially composes the apparatus of Geysirs, we must remember that silicic acid is also diffused in many cold springs which contain a very small portion of carbonic acid.

Acid springs and jets of carbonic acid gas, which were long ascribed to deposits of coal and lignite, appear rather to belong entirely to the processes of deep volcanic activity:—an activity which is universally disseminated, and therefore does not exert itself merely in those places where volcanic rocks testify to the existence of ancient local fiery eruptions. In extinguished volcanoes jets of carbonic acid certainly remain longest after the Plutonic catastrophes; they follow the stage of Solfatara activity; but nevertheless waters impregnated with carbonic acid, and of the most various temperatures, burst forth from granite, gneiss, and old and new floetz mountains. Acid springs become impregnated with alkaline carbonates, and especially with carbonate of soda, wherever water impregnated with carbonic acid acts upon rocks containing alkaline silicates.[55] In the north of Germany many of the carbonic acid springs and gaseous jets are particularly remarkable for the dislocation of the strata about them and for their eruption in circular valleys (Pyrmont, Driburg) which are usually completely closed. Friedrich Hoffman and Buckland have almost at the same time very characteristically denominated such depressions *valleys of elevation* (*Erhebungs-Thäler*).

In the springs to which the name of sulphurous waters is given, the sulphur by no means constantly occurs combined in the same way. In many, which contain no carbonate of soda, sulphuretted hydrogen is probably dissolved; in others, for example in the sulphurous waters of Aix (the Kaiser, Cornelius, Rose, and Quirinus springs), no sulphuretted hydrogen is contained, according to the precise experiments of Bunsen and Liebig, in the gases obtained by boiling the

quantity of oxygen to be only 0.299. We had previously found 0.31 of oxygen in meteoric waters (rain). Upon the nitrogen gas contained in the acid springs of Neris and Bourbon l'Archambault, see the works of Anglade and Longchamp (1834), and on carbonic acid exhalations in general, see Bischof's admirable investigations in his *Chemische Geologie*, Bd. i, s. 243—350.

[55] Bunsen, in Poggendorff's *Annalen*, Bd. lxxxiii, s. 257; Bischof, *Geologie*, Bd. i, s. 271.

waters without access of air; indeed the Kaiserquelle alone contains 0.31 per cent. of sulphuretted hydrogen in gas bubbles which rise spontaneously from the springs.[56]

A thermal spring which gives rise to an entire river of water acidified by sulphur, the Vinegar river (*Rio Vinagre*), called Pusambio by the aborigines, is a remarkable phenomenon to which I first called attention. The Rio Vinagre rises at an elevation of about 10,660 feet on the north-western declivity of the volcano of Purace, at the foot of which the city of Popayan is situated. It forms three picturesque cascades,[57] of one of which I have given a representation, falling over a steep trachytic wall probably 320 feet in perpendicular height. From the point where the small river falls into the Cauca, this great river for a distance of 2—3 miles (from 8 to 12 English miles) downwards, as far as the junctions of the Pindamon and Palacé, contains no fish; which must be a great inconvenience to the inhabitants of Popayan, who are strict observers of fasts! According to Boussingault's subsequent analysis, the waters of the Pusambio contain a great quantity of sulphuretted hydrogen and carbonic acid, with some sulphate of soda. Near the source, Boussingault found the temperature to be 163°. The upper part of the Pusambio runs underground. Degenhardt (of Clausthal in the Harz), whose early death has caused a great loss to Geognosy, discovered a hot spring in 1846 in the Paramo de Ruiz, on the declivity of the volcano of the same name, at the sources of the Rio Guali, and at an altitude of 12,150 feet, in the water of which Boussingault found three times as much sulphuric acid as in the Rio Vinagre.

The equability of the temperature and chemical constitu-

[56] Liebig and Bunsen, *Untersuchung der Aachener Schewefelquellen*, in the *Annalen der Chemie und Pharmacie*, Bd. lxxix (1851), s. 101. In the chemical analyses of mineral waters which contain sulphuret of sodium, carbonate of soda and sulphuretted hydrogen are often stated to occur from an excess of carbonic acid being present in those waters.

[57] One of these cascades is represented in my *Vues des Cordillères*, pl. xxx. On the analysis of the water of the Rio Vinagre, see Boussingault, in the *Annales de Chimie et de Physique*, 2e, série, t. lii, 1833, p. 397, and Dumas, 3e série, t. xviii, 1846, p. 503; on the spring in the Paramo de Ruiz, see Joaquin Acosta, *Viajes Cientificos á los Andes Ecuatoriales*, 1849, p. 89.

tion of springs as far as we can ascertain from reliable observations, is far more remarkable than the instability[58] which has been occasionally detected. The hot spring-waters, which, during their long and tortuous course, take up such a variety of constituents from the rocks with which they are in contact, and often carry them to places where they are deficient in the strata through which the springs burst forth, have also an action of a totally different nature. They exert a transforming and at the same time a formative activity, and in this respect they are of great geognostic importance. Senarmont has shown with wonderful acuteness, how extremely probable it is that many vein-crevices (ancient courses of thermal waters) have been filled from below upwards by

[58] The examples of alteration of temperature in the thermal springs of Mariara and las Trincheras lead to the question whether the Styx water, whose source, so difficult of access, is situated in the wild Aroanic Alps of Arcadia, near Nonacris, in the district of Pheneos, has lost its pernicious qualities by alteration in the subterranean fissures of supply? or whether the waters of the Styx have only occasionally been injurious to the wanderer by their icy coldness? Perhaps they are indebted for their evil reputation, which has been transmitted to the present inhabitants of Arcadia, only to the awful wildness and desolation of the neighbourhood, and to the myth of their origin from Tartarus. A young and learned philologist, Theodor Schwab, succeeded a few years ago, with great exertion, in penetrating to the rocky wall from which the spring trickles down, exactly as described by Homer, Hesiod, and Herodotus. He drank some of the water, which was extremely cold, but very pure to the taste, without perceiving any injurious effects (Schwab, *Arkadien, seine Natur und Geschichte,* 1852, s. 15—20). Amongst the ancients it was asserted that the coldness of the water of the Styx burst all vessels except those made of the hoof of an ass. The legends of the Styx are certainly very old, but the report of the poisonous properties of its spring appears to have been widely disseminated only in the time of Aristotle. According to a statement of Antigonus of Carystus (*Hist. Mirab.* § 174), it was contained very circumstantially in a book of Theophrastus, which has been lost to us. The calumnious fable of the poisoning of Alexander by the water of the Styx, which Aristotle communicated to Cassander by Antipater, was contradicted by Plutarch and Arrian, and disseminated by Vitruvius, Justin, and Quintus Curtius, but without mentioning the Stagirite (Stahr, *Aristotelia,* Th. i, 1830, s. 137—140). Pliny (xxx, 53) says, somewhat ambiguously :—" Magna Aristotelis infamia excogitatum." See Ernst Curtius, *Peloponnesus* (1851), Bd. i, s. 194—196, and 212; St. Croix, *Examen Critique des Anciens Historiens d'Alexandre,* p. 496. A representation of the cascade of the Styx, drawn from a distance, is contained in Fiedler's *Reise durch Griechenland,* Th. i, s. 400.

may, in accordance with the presumption to which the local conditions lead, have taken place in the valley of the Rhine, above Neuwied, in the great Neuwied basin, perhaps near Urmits, on the left bank of the Rhine. From the friability of the material the place of eruption may have disappeared without leaving any traces, by the subsequent action of the current of the Rhine. In the entire tract of the Maars of the Eifel, as in that of its volcanoes from Bertrich to Ormond, no pumice-stone is found. That of the Laacher lake is limited to the rocks upon its margin; and on the other Maars the small fragments of felspathic rock, which lie in the volcanic sand and tuff, do not pass into pumice."

We have already touched upon the relative antiquity of the Maars and of the eruptions of the lava-streams, which differ so much from them, compared with that of the formation of the valleys. "The trachyte of the Siebengebirge appears to be much older than the valley-formation, and even older than the Rhenish brown-coal. Its appearance has been independent of the cutting of the valley of the Rhine, even if we should ascribe this valley to the formation of a fissure. The formation of the valleys is more recent than the Rhenish brown-coal, and more recent than the Rhenish basalt; but older than the volcanic eruptions with lava-streams, and older than the great pumice-eruption and the Trass. Basalt formations decidedly extend to a more recent period than the formation of trachyte, and the principal mass of the basalt is, therefore, to be regarded as younger than the trachyte. In the present declivities of the valley of the Rhine many basaltic groups (the quarry of Unkel, Rolandseck, Godesberg), were only laid bare by the opening of the valley, as up to that time they were probably enclosed in the Devonian grauwacke rocks."

The Infusoria, whose universal diffusion, demonstrated by Ehrenberg, upon the continents, in the greatest depths of the sea and in the upper strata of the atmosphere, is one of the most brilliant discoveries of our time, have their principal seat in the volcanic Eifel, in the Rapilli, Trass-strata, and pumice-conglomerates. Organisms with silicious shields fill the valley of Brohl and the eruptive matters of Hochsimmer; sometimes, in the Trass, they are mixed with uncarbonised twigs of coniferæ. According to Ehrenberg, the

Amongst the isolated conical and bell-shaped mountains, which are there called volcanoes, many may, indeed, consist

name. The last eruption was that of 1656. The whole surrounding country is exposed to violent earthquakes; that of the 16th of April, 1854, which was preceded by no noises, overthrew nearly all the buildings in San Salvador.

Volcano of *Izalco*,* near the village of the same name, often producing ammonia. The first eruption recorded in history occurred on the 23rd February, 1770; the last widely-luminous eruptions were in April, 1798, 1805 to 1807, and 1825 (see above, p. 261, and Thompson, *Official Visit to Guatemala*, 1829, p. 512).

*Volcan de Pacaya** (lat. 14° 23′), about 14 miles to the south-east of the city of New Guatemala, on the small Alpine lake Amatitlan, a very active and often flaming volcano; an extended ridge with three domes. The great eruptions of 1565, 1651, 1671, 1677, and 1775 are known; the last, which produced much lava, is described by Juarros as an eye-witness.

Next follow the two volcanoes of Old Guatemala, with the singular appellations *de Agua* and *de Fuego*, near the coast, in latitude 14° 12′.

Volcan de Agua, a trachytic cone near Escuintla, higher than the Peak of Teneriffe, surrounded by masses of obsidian (indications of old eruptions?). The volcano, which reaches into the region of perpetual snow, has received its name from the circumstance that, in September, 1541, a great inundation (caused by earthquake and the melting of snow?) was ascribed to it; this destroyed the first established city of Guatemala, and led to the building of the second city, situated to the north-north-west, and now called *Antigua Guatemala*.

Volčan de Fuego,* near Acatenango, 23 miles in a west-north-west direction from the so-called water-volcano. With regard to their relative position, see the rare map of the Alcalde Mayor, Don José Rossi y Rubi, engraved in Guatemala, and sent to me thence as a present: *Bosquejo del espacio que media entre los estremos de la Provincia de Suchitepeques y la Capital de Guatemala*, 1800. The Volcan de Fuego is still active, but now much less so than formerly. The older great eruptions were those of 1581, 1586, 1623, 1705, 1710, 1717, 1732, 1737, and 1799; but it was not only these eruptions, but also the destructive earthquakes which accompanied them, that moved the Spanish Government in the second half of the last century to quit the second seat of the city (where the ruins of la Antigua Guatemala now stand), and compel the inhabitants to settle further to the north, in the new city of Santiago de Guatemala. In this case, as at the removal of Riobamba, and several other towns near the volcanoes of the chain of the Andes, a dogmatic and vehement dispute was carried on in reference to the difficult selection of a locality "of which it might be asserted, according to previous experience, that it was but little exposed to the action of neighbouring volcanoes (lava-streams, eruptions of scoriæ and

of trachyte and dolerite, but having always been unopened, have never exhibited any igneous activity since the time of their upheaval. *Eighteen* are to be regarded as still active; *seven* of these have thrown up flames, scoriæ and lava-streams in the present century (1825, 1835, 1848, and 1850); and *two*[67] at the end of the last century (1775 and 1799). The deficiency of lava-streams in the mighty volcanoes of the Cordilleras of Quito has recently given occasion to the repeated assertion that this deficiency is equally general in the volcanoes of Central America. Certainly, in the majority of cases, eruptions of scoriæ and ashes have been unaccompanied by any effusion of lava—as for exam-

earthquakes!)" In 1852, during a great eruption, the Volcan de Fuego poured forth a lava-stream towards the shore of the Pacific. Captain Basil Hall measured, under sail, both the volcanoes of Old Guatemala, and found for the Volcan de Fuego 14,665 feet, and for the Volcan de Agua, 14,903 feet. The foundation of this measurement has been tested by Poggendorff. He found the mean elevation of the two mountains to be less, and reduced it to about 13,109 feet.

*Volcan de Quesaltenango** (lat. 15° 10′), burning since 1821, and smoking, near the town of the same name; the three conical mountains which bound the Alpine lake Atitlan (in the mountain chain of Solola) on the south, are also said to be ignited. The volcano of *Tajamulco,* referred to by Juarros, certainly cannot be identical with the volcano of Quesaltenango, as the latter is at a distance of 40 geog. miles to the N.W., of the village of Tajamulco, to the south of Tejutla.

What are the two volcanoes of *Sacatepeques* and *Sapotitlan,* mentioned by Funel, or Brué's *Volcan de Amilpas?*

The great volcano of *Soconusco,* situated on the borders of Chiapa, 28 geog. miles to the south of Ciudad Real, in lat. 16° 2′.

At the close of this long note I think I must again mention that the barometric determinations of altitude here adduced are partly derived from Espinache, and partly borrowed from the writings and maps of Baily, Squier, and Molina.

67 The following 18 volcanoes, constituting therefore nearly the half of all those referred to by me as active in former or present times, are to be regarded as at present more or less active:—Irasu and Turrialva, near Cartago, el Rincon de la Vieja, Votos(?) and Orosi; the insular volcano Ometepec, Nindiri, Momotomba, el Nuevo, at the foot of the trachytic mountain Las Pilas, Telica, el Viejo, Conseguina, San Miguel Bosotlan, San Vicente, Izalco, Pacaya, Volcan de Fuego (de Guatemala), and Quesaltenango. The most recent eruptions are those of el Nuevo, near las Pilas, on the 18th April, 1850; San Miguel Bosotlan, 1848; Conseguina, and San Vicente, 1835; Izalco, 1825; Volcan de Fuego, near New Guatemala, 1799 and 1852; and Pacaya, 1775.

According to the tradition, the phenomena of small eruptions of water and mud which were observed during the first days simultaneously with the incandescent scoriæ, are ascribed to the destruction of two brooks, which, springing on the western declivity of the mountain of Santa Ines, and consequently to the east of the Cerro de Cuiche, abundantly irrigated the cane-fields of the former Hacienda de San Pedro de Jorullo, and flowed onwards far to the west to the Hacienda de la Presentacion. Near their origin, the point is still shown where they disappeared in a fissure with their formerly cold waters, during the elevation of the eastern border of the Malpais. Running below the Hornitos, they reappear, according to the general opinion of the people of the country, heated, in two thermal springs. As the elevated part of the Malpais is there almost perpendicular, they form two small waterfalls, which I have seen and represented in my drawing. For each of them the previous name, Rio de San Pedro and Rio de Cuitimba, has been retained. At this point I found the temperature of the steaming water to be 126°·8. During their long course the waters are only heated, but not acidulated. The test papers, which I usually carried about with me, underwent no change; but further on, near the Hacienda de la Presentacion, towards the Sierra de las Canoas, there flows a spring impregnated with sulphuretted hydrogen gas, which forms a basin of 20 feet in breadth.

In order to acquire a clear notion of the complicated outline and general form of the surface of the ground, in which such remarkable upheavals have taken place, we must distinguish hypsometrically and morphologically :—1. The position of the volcanic system of Jorullo in relation to the average level of the Mexican plateau ; 2. The convexity of the Malpais, which is covered by thousands of hornitos ; 3. The fissure upon which six large, volcanic, mountain-masses have arisen.

On the western portion of the Central Cordillera of Mexico, which strikes from S.S.E. to N.N.W., the plain of the Playas de Jorullo, at an elevation of only 2557 feet above the level of the Pacific, forms one of the horizontal mountain terraces, which, everywhere in the Cordilleras, interrupt the line of inclination of the declivity, and consequently more or less impede the decrease of heat in the superposed

a metallic lustre: others are basaltic and full of small granules of olivine. When we had thus ascended to the upper surface of the lava-stream at a perpendicular elevation of 711 feet, we turned to the white ash cone, on which, from its great steepness, we could not but fear that during frequent and rapid slips we might be seriously wounded by the rugged lava. The upper margin of the crater, on the south western part of which we placed the instruments, forms a ring of a few feet in width. We carried the barometer from the margin into the oval crater of the truncated cone. At an open fissure air streams forth of a temperature of 200°·6. We now stood 149 feet in perpendicular height below the margin of the crater; and the deepest point of the chasm, the attainment of which we were compelled to give up on account of the dense sulphurous vapours, appeared to be only about twice this depth. The geognostic discovery which had the most interest for us, was the finding of several white fragments, three or four inches in diameter, of a rock rich in felspar baked into the black basaltic lava. I regarded these at first[12] as syenite, but from the

[12] "M. Bonpland and myself were particularly astonished at finding, encased in the basaltic, lithoid and scorified lavas of the volcano of Jorullo, white or greenish white angular fragments of *Syenite*, composed of a little amphibole and a great quantity of lamellar felspar. Where these masses have been split by heat, the felspar has become filamentous, so that the margins of the crack are united in some places by fibres elongated from the mass. In the Cordilleras of South America, between Popayan and Almaguer, at the foot of the *Cerro Broncoso*, I have found actual fragments of *gneiss* encased in a trachyte abounding in pyroxene. These phenomena prove that the trachytic formations have issued from beneath the granitic crust of the globe. Analogous phenomena are presented by the trachytes of the *Siebengebirge* on the banks of the Rhine, and by the inferior strata of Phonolite (*Porphyrschiefer*) of the *Biliner Stein* in Bohemia." (Humboldt, *Essai Géognostique sur le Gisement des Roches*, 1823, pp. 133 and 339. Burkart also (*Aufenthalt und Reisen in Mexico*, Bd. i, s. 230) detected enclosed in the black lava, abounding in olivine, of Jorullo: "Blocks of a metamorphosed syenite. Hornblende is rarely to be recognized distinctly. The blocks of syenite may certainly furnish an incontrovertible proof, that the seat of the focus of the volcano of Jorullo is either in or below the syenite, which shows itself in considerable extent, a few miles (*leguas*) further south, on the left bank of the Rio de las Balsas, flowing into the Pacific Ocean." Dolomieu, and, in 1832, the excellent geognosist, Friedrich Hoffmann, found in Lipari, near

exact examination by Gustav Rose, of a fragment which I brought with me, they probably belong rather to the granite formation, which Burkart has also seen emerging from below the syenite of the Rio de las Balsas. "The inclosure is a mixture of quartz and felspar. The blackish green spots appear to be not hornblende, but mica fused with some felspar. The white fragment baked in is split by volcanic heat, and in the crack white, tooth-like, fused threads run from one margin to the other."

To the north of the great volcano and the scoriaceous lava mountain which it has vomited forth in the direction of the old basalt of the Cerro del Mortero, follow the two last of the six often-mentioned eruptions. These hills also were originally very active, for the people still call the extreme mountain of ashes, *el Volcancito.* A broad fissure opened towards the west, bears the traces of a destroyed crater. The great volcano, like the Epomeo in Ischia, appears to have only once poured out a mighty lava-stream. That its lava-pouring activity endured after the period of its first eruption, is not proved historically; for the valuable letter, so happily discovered, of Father Joaquin de Ansogorri, written scarcely three weeks after the first eruption, treats almost exclusively of the means of making "arrangements for the better pastoral care of the country people who had fled from the catastrophe and become dispersed;" and for the following thirty years we have no records. As the tradition speaks very generally of fires which covered so great a surface, it is certainly to be supposed that all the six hills upon the great fissure, and the portion of the Malpais itself in which the Hornitos have appeared, were simultaneously in combustion. The temperature of the surrounding air, which I measured, allows us to judge of the heat which prevailed there 43 years previously; they remind one of the former condition of our planet, in which the temperature of its atmospheric envelope, and with this the distribution of organic life, might be modified by the thermic action of the interior by means of deep fissures (under any latitude and for long periods of time).

Caneto, fragments of granite, formed of pale red felspar, black mica, and a little pale gray quartz, enclosed in compact masses of obsidian (Poggendorff's *Annalen der Physik*, Bd. xxvi, s. 49).

earth's crust, might, in my opinion, offer a greater appearance of probability. It is not difficult to imagine that at the margins of the up-heaving continents which now form the more or less precipitous littoral boundary visible over the surface of the sea, fissures have been produced by the simultaneous sinking of the adjoining bottom of the sea, through which the communication with the molten interior is promoted. On the ridge of the elevations, far from that area of depression in the oceanic basin, the same occasion for the existence of such rents does not exist. Volcanoes follow the present sea-shore in single, sometimes double, and sometimes even triple parallel rows. These are connected by short chains of mountains, raised on transverse fissures, and forming mountain-nodes. The range nearest to the shore is frequently (but by no means always) the most active, while the more distant, those more in the interior of the country, appear to be extinct or approaching extinction. It is sometimes thought that, in a particular direction in one and the same range of volcanoes, an increase or diminution in the frequency of the eruptions may be perceived, but the phenomena of renewed activity after long intervals of rest render this perception very uncertain.

As many incorrect statements of the distance of volcanic activity from the sea are circulated, either through ignorance of, or inattention to, the exact localities both of the volcanoes and of the nearest points of the coast, I shall here give the following distances in geographical miles (each being equal to about 2030 yards, or 60 to a degree):—In the Cordilleras of Quito, the volcano of Sangay, which discharges uninterruptedly, is situated in the most easterly direction, but its distance from the sea is still 112 miles. Some very intelligent monks attached to the mission of the Indios Andaquies at the Alto Putumayo have assured me that on the upper Rio de la Fragua,[41] a tributary of the Caqueta, to the eastward of the Ceja, they had seen smoke issue from a conical moun-

[41] The position of the Volcan de la Fragua, as reduced at Timana, is N. L. 1° 48′, long. 75° 30′ nearly. Compare the *Carte Hypsométrique des Nœuds de Montagnes dans les Cordillères*, in the large atlas of my travels, 1831, pl. 5, see also pl. 22 and 24. This mountain, lying isolated and so far to the east, ought to be visited by a geologist capable of determining the longitude and latitude astronomically.

tain of no great height, and whose distance from the coast must have been 160 miles. The Mexican volcano of Jorullo, which was elevated above the surface in September, 1759, is 84 miles from the nearest point of the sea-shore (see above, pp. 314–321); the volcano of Popocatepetl is 132 miles; an extinct volcano in the eastern Cordilleras of Bolivia, near S. Pedro de Cacha, in the vale of Yucay (see above, p. 295), is upwards of 180 miles; the volcanoes of the Siebengebirge, near Bonn, and of the Eifel (see above, p. 231—238), are from 132 to 152 miles; those of Auvergne, Velay, and Vivarais,[42] distributing them into three separate groups (the group of the Puy de Dôme, near Clermont, with the Mont Dore, the group of the Cantal, and the group of the Puy and Mezenc), are severally 148, 116, and 84 miles distant from the sea. The extinct volcanoes of Olot, south of the Pyrenees, west of Gerona, with their distinct and sometimes divided lava-streams, are distant only 28 miles from the Catalonian shores of the Mediterranean, while, on the other hand, the undoubted, and to all appearances very lately extinct, volcanoes in the long chain of the Rocky Mountains, in the north-west of America, are situated at a distance of from 600 to 680 miles from the shore of the Pacific.

A very abnormal phenomenon in the geographical distribution of volcanoes is the existence in historical times of active, and partially, perhaps, even of burning volcanoes in the mountain-chain of the Thian-shan (the Celestial Mountains), between the two parallel chains of the Altai and the Kuen-lün. The existence of these volcanoes was first made known by Abel-Rémusat and Klaproth, and I have been enabled, by the aid of the able and laborious investigations of

[42] In these three groups which, according to the old geographical nomenclature, belong to Auvergne, the Vivarais, and the Velay, the distances given in the text are those of the northernmost parts of each group as taken from the Mediterranean Sea (between the Golfe d'Aigues Mortes and Cette). In the first group, that of the Puy de Dôme, a crater erupted in the granite near Manzat, called Le Gour de Tazena, is taken as the most northerly point (Rozet, in the *Mém. de la Société Géol. de France*, t. i, 1844, p. 119). Farther south than the group of the Cantal, and therefore nearest the sea-shore, lies the small volcanic district of la Guiolle near the Monts d'Aubrac, north-west of Chirac, and distant scarcely 72 geographical miles from the sea. Compare the *Carte Géologique de la France*, 1841.

themselves. An investigation which has now been long looked for in vain, founded on accurate experiments, exclusively directed to these escaping gaseous fluids, would lead to an invaluable extension of our knowledge of the geology of volcanoes, if at the same time attention were paid to the operation of the sea-water in subterranean formations, and to the great quantity of carburetted hydrogen belonging to the commingled organic substances.

The facts which I have brought together at the end of this section, the enumeration of those volcanoes which produce pumice without obsidian, and those which yield a great deal of obsidian and no pumice,—the remarkable, not constant, but very diversified association of obsidian and pumice with certain other minerals, early led me, during my residence in the Cordilleras of Quito, to the conclusion that the formation of pumice is the result of a chemical process, which may be verified in trachytes of very heterogeneous composition, without the necessity of a previous intervention of obsidian (that is to say, without its pre-existence in large masses). The conditions under which such a process is performed on a large scale, are perhaps founded (I would here repeat) less on the diversity of the material than on the gradation of heat, the pressure determined by the depth, the fluidity, and the length of time occupied in solidification. The striking, though rare, phenomena presented by the isolation of immense subterraneous pumice-quarries, far from any volcanic structures (conical and bell-shaped mountains), lead me at the same time to conjecture[22] that a not inconsiderable—perhaps even, in regard to volume, the greater, number of the volcanic rocks have been erupted, not from upraised volcanic structures, but from a net-work of fissures on the surface of the earth frequently covering over in the form of strata a space of many square miles. To these probably belong those masses of trap of the lower Silurian formation of the south-west of England, by the chronometric determination of which my worthy friend, Sir Roderic Murchison, has so greatly increased and heightened our acquaintance with the geological construction of the globe.

[22] See above, pp. 308, 330 332—336, 344—346, 354. For particulars respecting the geographical distribution of pumice and obsidian in the tropical zone of the New Continent, see Humboldt, *Essai Géognostique sur le gisement des Roches, &c.*, 1823, pp. 340—342, and 344—347.

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